Brodric Young
ECEN 350
BJT Amplifier Lab

ECEN 350 – BJT Amplifier Lab (50 points)
(jas, BJT Amplifier Lab.docx, 12/28/2024)

Note: You can work in pairs if desired on this lab, although no three person teams are allowed. Submit an electronic version of a lab report to receive credit for doing this lab. The goal of your **lab report is to provide sufficient documentation so that the lab can be repeated if necessary**. Therefore, simply add to this document to arrive at your lab report, as all of the explanatory text, procedures, and Discussion and Conclusion questions contained in this document are required for a complete lab report. So, for your lab report, **add a cover page that includes name or names, class and name of the lab. Also add in your results, and answers to the Discussion and Conclusions questions to the existing lab document**. While you are to share all **Procedure** items with your lab partner if you worked in a pair, your **Discussion and Conclusions** section is to be uniquely yours and not a copy of your lab partners. See the grading rubric at the end of this document for more details.

Purpose: To construct and characterize a voltage divider biased BJT amplifier employing ac emitter feedback.

Parts and Equipment:

1 – 2N3904 npn transistor.
1 – 120 Ω resistor.
1 – 470 Ω resistor.
1 – 680 Ω resistor.
1 – 2.7 kΩ resistor.
1 – 3.9 kΩ resistor.
1 – 100 kΩ resistor.
1 – 0.1 μF Capacitor
1 – 1 μF, 50 V capacitor.
1 – 10 μF, 50 V capacitor.
1 – 22 μF, 50 V capacitor.
1 – Portable Digital Multimeter (DMM)
1 - VirtualBench Measurement System and Computer.
2 - 1X/10X Probes for the VirtualBench MSO.
1 – BNC to alligator or micro-grabber cable for VirtualBench FGEN output.
1 - Breadboard.

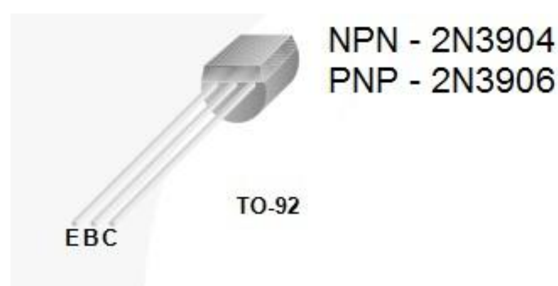


Figure 1: Pin-out for 2N3904 npn transistors.

Solderless Breadboards

A solderless breadboard is illustrated in **Figure 2a**, with the rows and columns of holes connected internally as shown in **Figure 2b**. The two pair of long rows labeled + and – are intended to provide easy access to power and ground. Hence, connecting the external power supply to one of the long rows labeled + and – provides convenient access to power and ground when several power and ground connections are required.

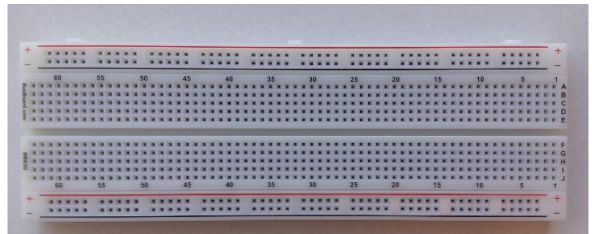


Figure 2a: Solderless Breadboard Hole Pattern.

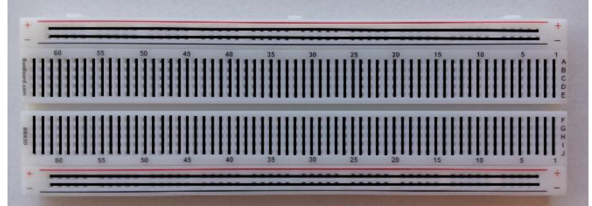


Figure 2b: Solderless Breadboard Internal Electrical Connections.

Through-hole components can be inserted and connected in the desired configuration on a solderless breadboard using the internal electrical connections shown in **Figure 2b**, along with various length hook-up wires illustrated in **Figure 3**. Try and minimize the length of hook-up wires for better circuit performance. Also, hook-up wires with the stripped and tinned leads produce more reliable circuits than the hook-up wires with the pins on the end. Please do not repurpose the hook-up wires for other projects.

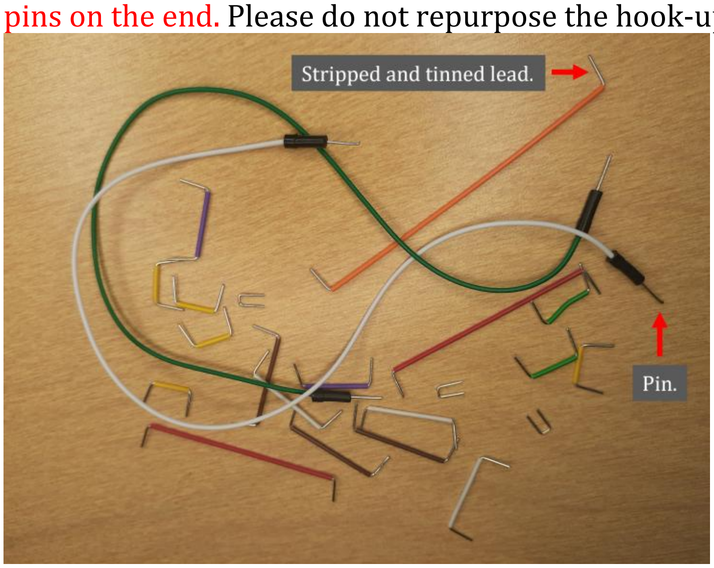


Figure 3: Hook-up Wires for Solderless Breadboards.

<u>Procedure:</u>

Part 1 – Amplifier Hand Calculations.

1. For the **Figure 4** circuit, hand calculate V_B using simplified analysis, followed by I_E, r_c, r'_e and $\mathbf{A_V}$, along with $|\mathbf{A_v}|_{dB}$ calculated as $20\log_{10}(|\mathbf{A_v}|)$, including your results below in **Table 1**. Note: The ac voltage gain $\mathbf{A_V}$ is a unitless negative quantity for an inverting amplifier, whereas $20\log_{10}(|\mathbf{A_v}|)$ is a positive quantity with units of dB. (12 points.)

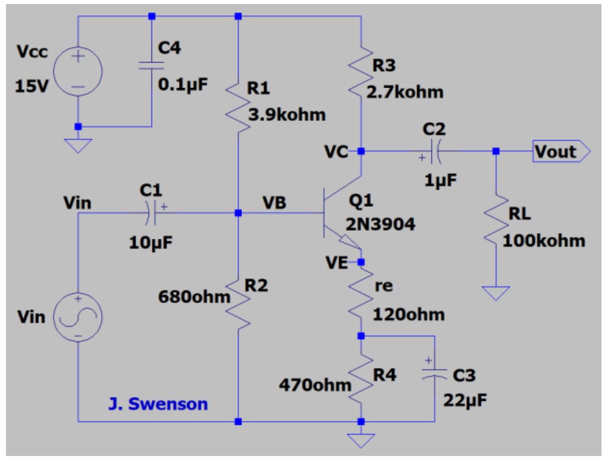


Figure 4: BJT Amplifier Circuit to be Analyzed for this Lab.

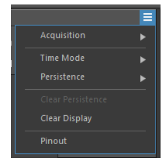
Table 1: Small-Signal Model Parameters for the Common-Emitter Amplifier of Figure 1.

V_B	I_E	r_c	r'_e	$\mathbf{A_v}$	$\lvert\mathbf{A_v}\rvert_{dB}$
2.23V	2.59mA	2629Ω	9.66Ω	-272	48.7

Part 2 – AC Analysis.

1. Connect up the BJT amplifier circuit of **Figure 4** on a breadboard, with V_{in} provided by a VirtualBench function generator (FGEN) output. For the polarized capacitors, the lead adjacent to a negative polarity stripe on the body of the part indicates the negative lead, which is to correspond to the curved plate on the schematic symbol.
2. Connect the oscilloscope probe with the red marking bands to Channel 1 (CH 1) and the oscilloscope probe with the yellow marking bands to Channel 2 (CH 2) on the VirtualBench CH 1 and CH 2 oscilloscope BNC connectors. Make sure the slide switches at the probe tip end of the oscilloscope probes are set to 10X versus 1X.
3. Start up the VirtualBench user interface software and for the CH 1 and CH 2 settings  make sure that both are set for AC coupling and 10X probe attenuation.
4. Set the VirtualBench Function Generator to output a 10 Hz, 200 mV peak-to-peak sine wave, and connect the BNC to alligator or micro-grabber cable so as to provide the input voltage V_{in} as indicated in **Figure 4**.
5. Connect up both channels on the oscilloscope, with CH 1 to monitor V_{out} and CH 2 to monitor V_{in} for the **Figure 4** circuit, with the V_{in} signal (CH 2) set as the trigger source.

6. In the **Trigger** menu, select CH 2 as the trigger source, and choose **Noise Reject** in the **Trigger** menu, which helps with triggering on low-level signals associated with low frequencies applied to the amplifier.
7. Obtain reasonable waveforms on the oscilloscope for the 10 Hz, 200 mV amplifier sinusoidal input voltage, along with the amplifier output voltage. At 10 Hz the amplifier output voltage should be larger than the input voltage, but less than indicated by the magnitude of A_V previously calculated because the coupling and bypass capacitors don't provide good coupling and bypassing at 10 Hz.
8. After achieving reasonable waveforms on the oscilloscope for a 10 Hz, 200 mV input sinusoid, select the **Acquisition** option from the pull-down menu in the upper right-hand corner of the oscilloscope user interface screen and choose **Acquisition → 16 Averaged** to reduce random measurement noise. Using the VirtualBench built-in oscilloscope waveform measurements, add a **Peak-to-Peak** Waveform Measurement to CH 1. The oscilloscopes automatic **peak-to-peak** measurement function does not work well on relatively small signals because of noise, and so use the waveform cursors instead to measure the CH 2 peak-to-peak voltage V_{in}. To do so set the cursor type as **Voltage** and position the two waveform cursors to provide the voltage difference ΔY, that represents the average peak-to-peak voltage of the signal at V_{in} in **Figure 4**. Record this cursor measured peak-to-peak value as $V_{in\_p\text{-}p}$ in **Table 1** below, adjusting the cursors as necessary for the different input frequencies. Also, for each input frequency listed in **Table 1** below, record the CH 1 **Peak-to-Peak** Waveform Measurement as $V_{out\_p\text{-}k}$ in the table. While the VirtualBench **Peak-to-Peak** Waveform Measurement is not accurate for low-level signals, those automatic waveform measurements are sufficient for the $V_{out\_p\text{-}k}$ data to be included in **Table 1**, as relatively low-level $V_{out\_p\text{-}k}$ signals only occur for very low and very high frequencies. (Note: With **16 Averaged** selected, it is necessary to wait several seconds after changing input frequencies for the oscilloscope to acquire 16 new measurements for averaging.)



9. Complete **Table 1** below for each of the input frequencies listed, adjusting the frequency of the FGEN output accordingly. Be sure to include units for $V_{in\_p\text{-}p}$ and $V_{out\_p\text{-}p}$ values, either by adding them once to each column label at the top or to each measured value. While the voltage ratio $V_{out\_p\text{-}p}/V_{in\_p\text{-}p}$ is dimensionless, dB voltage gain assigns the unit dB to this dimensionless ratio. (Note: Instead of using the ratio of peak values for the voltage gain magnitude, a ratio of peak-to-peak values are used in **Table 1**, as they are easier to measure and yield the same results.) (13 points.)
10. For the 10 kHz frequency data points, include an oscilloscope screen capture of your measured results, like the one shown below in **Figure 6**.

Table 1: Measured Data for the npn Common-Emitter Amplifier.

Input Frequency	$V_{in\_p\text{-}p}$	$V_{out\_p\text{-}p}$	$\lvert \mathbf{A_v} \rvert = V_{out\_p\text{-}p}/V_{in\_p\text{-}p}$	$\lvert \mathbf{A_v} \rvert_{dB}$ [1]
10 Hz	0.197 V	0.291 V	1.48	3.39 dB
30 Hz	0.197 V	1.00 V	5.08	14.1 dB
100 Hz	0.197 V	2.56 V	13.0	22.3 dB
300 Hz	0.197 V	3.27 V	16.6	24.4 dB
1 kHz	0.197 V	3.43 V	17.4	24.8 dB
10 kHz	0.197 V	3.45 V	17.5	24.9 dB
30 kHz	0.197 V	3.44 V	17.5	24.8 dB
100 kHz	0.197 V	3.43 V	17.4	24.8 dB
300 kHz	0.197 V	3.38 V	17.2	24.7 dB
1 MHz	0.197 V	3.17 V	16.1	24.1 dB
2 MHz	0.197 V	2.66 V	13.5	22.6 dB
5 MHz	0.197 V	1.55 V	7.87	17.9 dB
10 MHz	0.197 V	0.825 V	4.19	12.4 dB

1 – Voltage Gain Magnitude $\lvert \mathbf{A_v} \rvert_{dB} = 20\log_{10}\left(V_{out\_p-p}/V_{in\_p-p}\right)$.

11. Based on your **Table 1** data, plot the magnitude in dB on the vertical axis versus frequency on the horizontal axis, using a logarithmic scale for the frequency, which is a Bode magnitude plot. The MATLAB **semilogx**() plot command can be used to provide the logarithmic frequency axis scale if you choose to use MATLAB. Include the label "Frequency (Hz)" for the horizontal axis and "Gain Magnitude dB" for the vertical axis, along with the title "Gain Magnitude versus Frequency of a BJT Amplifier – Your Name or Names". Replace the plot below with your version, keeping the figure number and caption. (6 points.)

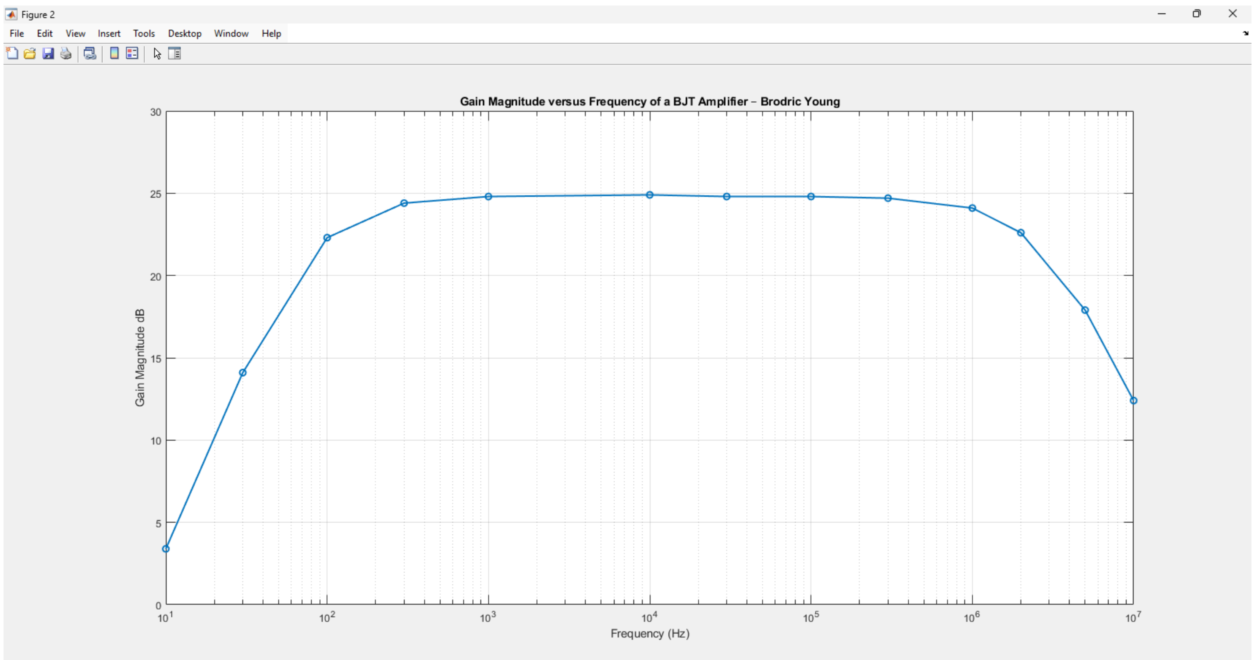


Figure 5: Frequency Response of the BJT Amplifier of **Figure 4**.

12. Replace the BJT amplifier response at 10 kHz screen capture in **Figure 6** below with your version, leaving in the figure number and caption. (6 Points.)

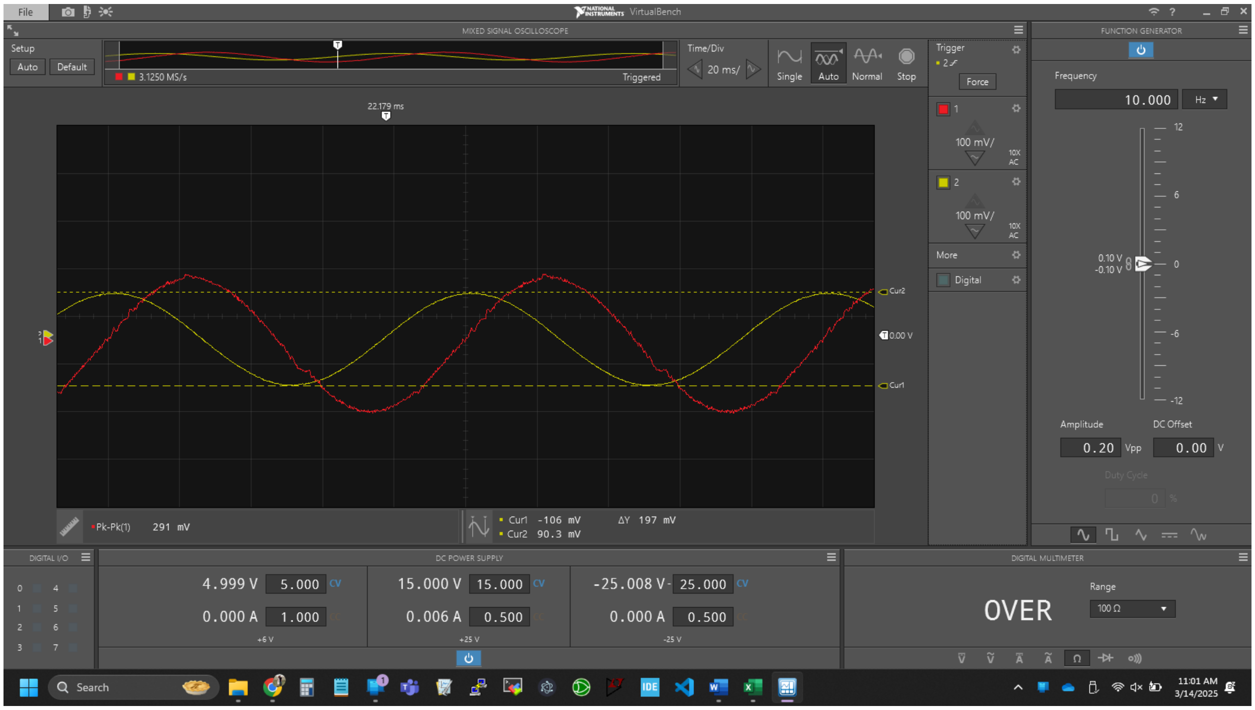


Figure 6: Input and Output Sinusoids at 10 kHz for the BJT Amplifier of **Figure 4**.

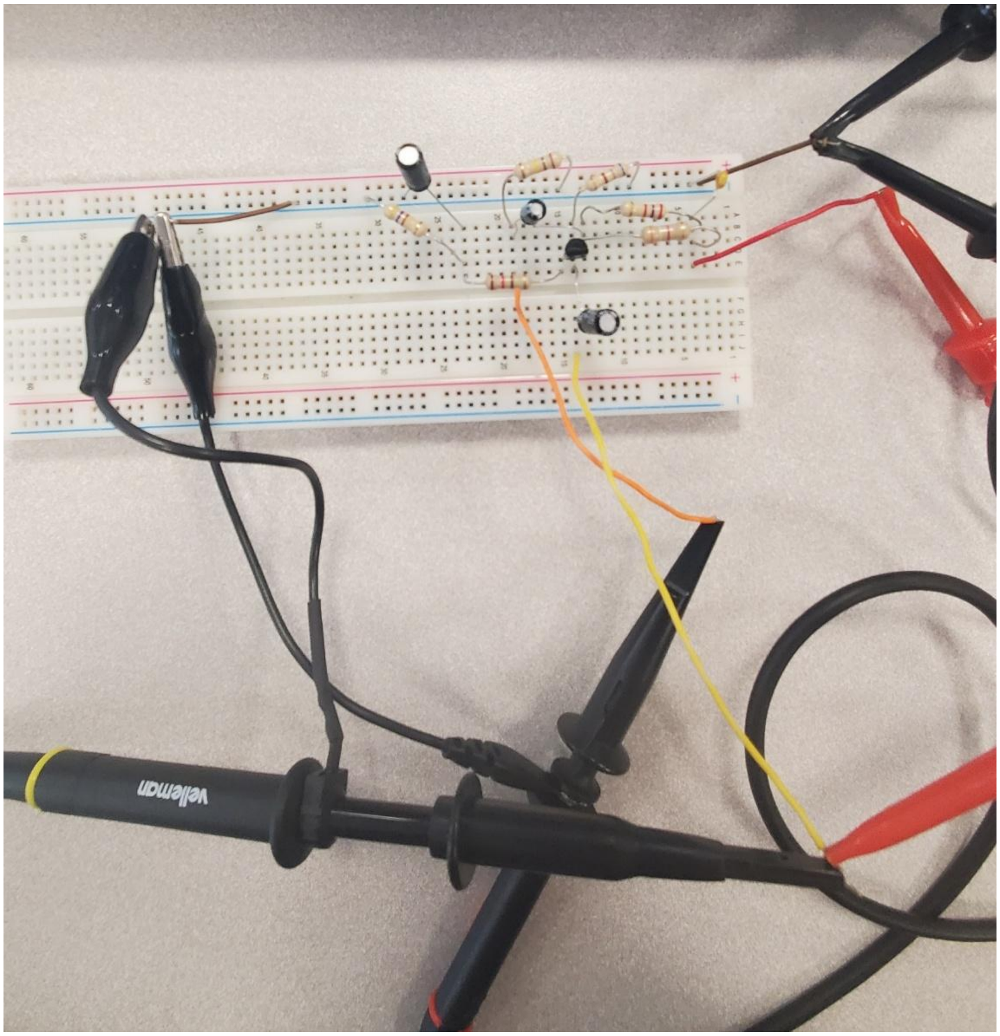


Figure 7: Wiring Implementation for the BJT Amplifier of **Figure 4**.

<u>**Discussion and Conclusions Questions:**</u> (For the following questions use your own words along with complete sentences. Points are to be deducted for AI generated answers.)

1. Why is the calculated small-signal gain negative for the BJT amplifier circuit of **Figure 4**? (2 Points.)

The negative sign means there is a 180^0 phase shift. My waveforms in figure 6 are a little off but ideally the output voltage peak will be lined up with the input voltage valley showing that the output is shifted 180^0 from the input.

2. For the BJT Amplifier Circuit of **Figure 4**, describe the function of capacitor C1, along with how the capacitor behaves at dc and the ac frequencies of interest. (3 Points.)

   Having a capacitor between the AC input and the base of the transistor allows the AC signal to pass through while blocking any DC component. This allows the voltage at the base of the transistor (V_B) to remain constant and keep the bias and voltage where we want it. With DC, the capacitor will act as an open circuit, completely blocking any DC current from passing through it. At low AC frequencies the capacitor has high reactance which partially blocks the signal and reduces the gain while at mid-high AC frequencies it has low reactance allowing the signal to pass through well resulting in a larger gain.

3. For the BJT Amplifier Circuit of **Figure 4**, describe the function of capacitor C3, along with how the capacitor behaves at dc and the ac frequencies of interest. (3 Points.)

   The bypassing capacitor C3's job is similar to C1 in that it's to allow AC signals to pass through while keeping the DC bias and voltages the same. Without the capacitor, R_E provides negative feedback which reduces the gain but with the capacitor at AC frequencies it shorts out R_E removing the negative feedback and increasing the gain while keeping the DC bias the same.

LTspice Common-Emitter Amplifier Lab Grading Rubric: Submit an electronic version of a lab report to receive credit for doing this lab. The goal of your **lab report is to provide sufficient documentation so that the lab can be repeated if necessary**. Therefore, simply add to this document to arrive at your lab report, as all the explanatory text, procedures, and Discussion and Conclusion questions contained in this document are required for a complete lab report. So, for your lab report, **add a cover page that includes name or names, class and name of the lab. Also add in your results, and answers to the Discussion and Conclusions questions to the existing lab document.** While you are to share all **Procedure** items with your lab partner if you worked in a pair, your **Discussion and Conclusions** section is to be uniquely yours and not a copy of your lab partners.

Lab Report Item	Points
Cover Page	2
Part 1 – Amplifier Hand Calculations. **Table 1**: (12 points total. 2 points per entry, -0.5 points per missing units or sign error, with A_v being unitless.)	12
Part 2 – AC Analysis. **Table 1**: (13 points total. 0.25 points per entry, -0.1 points for each incorrect or missing unit.) **Figure 5**: (6 points total. 2 points for using a logarithmic frequency axis, 1 point for using dB magnitude data from **Table 1**, 1 point for x-axis label including units, 1 point for y-axis label including units, 1 point for title including name or names.) **Figure 6**: (6 points total. 4 points for correct looking traces, 1 point for voltage cursors attached to CH 2 V_{in} trace, 1 point for Pk-Pk measurement associated with CH 1 V_{out} trace.)	25
Discussion and Conclusions	8
Grammar and Professionalism	3
Total	50

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